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16. ABSTRACT
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Effects of Acid Rain on Apple Tree Productivity and Fruit Quality[1]

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Abstract. **Mature 'McIntosh', 'Empire', and 'Golden Delicious' apple trees (*Malus domestica* Borkh.) were sprayed with simulated acid rain solutions in the pH range of 2.5 to 5.5 at full bloom in 1980 and in 1981. In 1981, weekly sprays were applied at pH 2.75 and pH 3.25. Necrotic lesions developed on apple petals at pH 2.5 with slight injury appearing at pH 3.0 and pH 3.5. Apple foliage had no acid rain lesions at any of the pH levels tested. Pollen germination was reduced at pH 2.5 in 'Empire'. Slight fruit set reduction at pH 2.5 was observed in 'McIntosh'. The incidence of russetting on 'Golden Delicious' fruits was ameliorated by the presence of rain-exclusion chambers but was not affected by acid rain. With season-long sprays at pH 2.75, there was a slight delay in maturity and lower weight of 'McIntosh' apples. Even at the lowest pH levels no detrimental effects of simulated acid rain were found on apple tree productivity and fruit quality when measured as fruit set, seed number per fruit, and fruit size and appearance.**

As a result of favorable climatic factors, apples are grown extensively in New York State and rank second in national apple production with the annual harvest approaching a value of 60 million dollars. However, with unstable marketing climate, New York growers have seen average net economic losses per acre in a number of recent years (29). Environmental stress effects, such as air pollution or acid rain, could be the difference between profit and loss. New York and other northeast states are directly downwind from air masses moving through the industrial midwest. High levels of ozone (O_3) in rural areas of New York are directly associated with the movement of these air masses (26). Precursors of acid precipitation are associated with these same air masses. Therefore, New York apple trees may be vulnerable to the effects of air pollution in an otherwise suitable climatic area. We have studied simulated acid rain effects on grapevines and found reduction in fruit set and soluble solids at subambient pH levels (12).

Apples have generally been considered to be less susceptible to air pollutants than grapes (25); however, injury by O_3 and SO_2 on apple trees under laboratory conditions has been reported (17, 20, 25). Przybylski examined the effects of SO_2, SO_3, and H_2SO_4 from sulfur mines on apple, plum, and sweet cherry trees (23) and found that both apple foliage and flowers were injured on trees 0.5 to 1.0 km from a sulfur factory. Apple foliar injury varied with cultivar and age. Apple flowers showed necrosis on petals and pistils. The pH of the acid mist or rain contacting the trees was not recorded. In addition to the acute and chronic exposure that annual herbaceous plants are subject to in one season, perennial plants are exposed to acute and chronic pollutants year after year. The reproductive cycle of fruit crops is initiated the year prior to harvest in the mature tree or vine (4, 24); therefore, air pollutants may influence the fruiting process at the time of flower initiation in year 1 or following fertilization, fruit set, fruit development and maturation stages in year 2. The bloom period is of brief duration in the spring and is very vulnerable to external influences. Air pollutants such as O_3 (11) and SO_2 (16, 27) have reduced pollen germination in various plants. Sulfur dioxide has also reduced seed set (21). An episode of acid rain during this critical period could also influence pollen germination and seed or fruit set of apples.

Apple trees produce relatively large (2–3 cm), attractive flowers which are perfect but self-incompatible. Cross-pollination from other apple cultivars or from other *Malus* species such as crab apples is required for fruit set. Insect pollination is necessary in apples, since wind does not readily carry apple pollen (28). Rainfall during apple bloom has been associated with low fruit set. This has frequently been attributed to reduced pollination by honey bees (28). Reduced pollination may also reduce apple seed number, which is related to reduced fruit weight (1).

Marketability of fruits may also be impaired by acid rain, as evidenced by russetting of 'Golden Delicious' apple fruits (7). However, it is rainfall alone, whether acidic or not, that induces russetting (6, 10). Other surface disorders on apples may be caused by O_3 (5). Acid rain was examined as a causal agent in the decline of calcium in apple leaf samples analyzed over several years in New York (2, 3). Although acid rain leached calcium from apple leaves, the leaves recovered the lost calcium within 1 week after treatment stopped; therefore, it was concluded that the decline of calcium in leaf samples was not caused by acid rain.

Crop responses to acid precipitation vary with species (1, 19). At pH levels between 4 and 3 many effects, both positive and negative, have been demonstrated. At pH below 3, the chances of harmful effects on growth or yield are substantially increased (15). Foliage of broadleaved herbaceous plants was found to be more sensitive to acidity in rainfalls than that of broadleaved woody plants or conifers (9, 13, 18). Lesion development on *Betula* leaves has been reported at pH 2.8 (22). Injury by rain acidity was also seen in *Poplar* (8) and *Malus hupehensis* (un-

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published data). The objective of this research was to examine the effects of acid rain on fruit production in apples with emphasis on flowering, pollen germination, fruit set, fruit development, and fruit quality. Background ions in mg/liter were 4.46 SO_4, 1.95 NO_3, 0.37 NH_4, 0.28 Ca, 0.056 Mg, 0.074 K, 0.183 Na, and 0.168 Cl. The data are precipitation volume-weighted averages for the 26-week period from April 17 to Oct. 15, 1979. The pH averaged 4.37 during this period. Stock solutions were prepared by adding the prescribed background ion content to distilled water. Acidity for the various treatments was adjusted by adding concentrated reagent grade acids in a volumetric ratio of 2 parts sulfuric to 1 part nitric acid. In the area of this study, rain during the growing season occurs in about this same 2:1 sulfuric to nitric ratio.

Materials and Methods

Since the composition of ambient rain episodes varies widely in the Northeast (14), the background ion contents of simulated acid rain solutions were matched to local imput conditions. For our experiments at Geneva, N.Y., local precipitation chemistry data were obtained from Warren Knapp, Cornell Univ. (personal communication).

The pH of each rainfall at the experiment site during the 1980 and 1981 seasons was measured (Table 1). Treatments were applied with "Killaspray" garden-type, hand-pumped, compressed-air sprayers (ASL, Ltd. of Birmingham, England). Droplet size and intensity were regulated by altering the nozzle or internal pressure of the sprayer. Orchard trees were divided into quadrants with each quadrant receiving a different pH treatment. This design was used to reduce the statistical error which could result from between-tree variability in response to the pH treatments.

Table 1. Ambient rainfall (amount and pH) during field experiments at Geneva, N.Y., in 1980 and 1981.

Date	Rainfall (mm)	pH[z]
1980		
5-13[y]	11	4.1
5-19[y]	10	5.1
6-09	38	4.2
6-10	7	4.6
1981		
5-06	2	3.8
5-11[y]	6	4.4
5-12[y]	9	4.4
5-15[y]	13	4.4
5-16[y]	11	4.0
5-27	3	4.1
5-30	4	4.0
6-03	5	4.1
6-07	4	5.0
6-09	7	5.6
6-10	2	4.6
6-15	15	5.5
6-16	8	5.2
6-23	14	4.2
6-25	6	7.0
7-01	3	5.8
7-02	2	5.4
7-05	7	5.2
7-06	5	5.0
7-20	19	4.0
7-21	4	3.8
7-27	8	3.5
7-28	7	3.3
8-04	12	3.5
8-08	11	4.3
8-10	10	3.9
9-02	16	4.2

[z]Acidity of total amount collected; during the rain episode, pH may have been < or > this value.
[y]Rain occurred during anthesis.

Initial experiments in 1980 involved field studies to examine the effects of simulated acid rain treatments, supplemental to ambient rainfall, on flowering. The effects of: 1) various strengths of simulated acid rain (pH); 2) timing of acid rain episodes; and 3) cultivar responses were determined. Solutions ranging in pH from 2.5 to 5.5 were applied prebloom and at bloom to 'McIntosh' and 'Empire' on M 7 rootstock and 'Golden Delicious' on M 2.

The effect of pH on pollen germination was investigated. Anthers were exposed to several acid rain treatments before pollen germination was analyzed. After air-drying, the 'Empire' pollen was germinated on 12% sucrose agar plates. The preparations were flooded with 1% acetocarmine after a 4-hr dark incubation and counted for germination. 'McIntosh' and 'Golden Delicious' pollen germinated poorly.

To afford greater precision of treatment on follow-up experiments in 1981, exclusion chambers made of 8-mil PVC film covering wood frames were used to test treatments independently of ambient rain. An exclusion chamber with the ends open within the row was erected over each of two 15-year-old 'Golden Delicious' apple trees on M 2 rootstock. Light levels in the chamber at full sunlight were reduced by about 20%.

Seven branches with flower clusters were tagged in each tree quadrant. Before bloom each flower cluster was reduced to the 3 most uniform blossoms. Solutions of pH 3.0 and pH 4.0 were sprayed at full bloom, keeping the branches wet from 0800 to 1700 HR by spraying every half hour. Pollen germination, fruit set, seed production, fruit condition (including russetting), and the incidence of disease such as powdery mildew and fire blight were evaluated.

A separate study was conducted in 1981 on 16 'Golden Delicious' apple trees on M 2 rootstock, with all receiving ambient rain. Treatments included ambient rainfall and supplemental acidic solutions at pH 2, 5, 3.0, 3.5, 4.0, 4.5, and 5.0. The 6 simulated acid rain treatments were replicated 8 times, and the ambient

Fig. 1. Necrotic lesions on 'Empire' apple flowers after simulated acid rain application at pH 2.5.

Table 2. Pollen germination and fruit set of apples after spray at bloom in 1980 with acid rain solutions. Data for fruit set in 'McIntosh' and 'Empire' transformed to log values and adjusted for analysis of covariance with total number of flowers.

Acid rain solution (pH)	Pollen germ. (%)	Fruit set (%)		
	Empire	McIntosh	Empire	Golden Delicious
2.5	8.4 c[z]	19.5 b	19.5 a	26.5 a
3.5	16.5 b	29.4 ab	24.2 a	26.3 a
4.5	19.4 ab	29.0 ab	26.0 a	26.0 a
5.5	16.9 b	31.8 a	24.5 a	29.8 a
Control (ambient rainfall)	27.0 a	---[y]	24.8 a	---[y]

[z]Means within columns separated by Duncan's multiple range test, 5% level.
[y]Data uncollected.

rainfall treatments were replicated 16 times. The same parameters were studied as in the study involving the ambient rain exclusion chambers. Applications at the same pH in the ambient rain-excluded trees were compared with those in the ambient rain-exposed trees.

A season-long chronic acid rain study was made on 15-year-old 'Golden Delicious' apple trees on M 2 rootstock and 'McIntosh' on M 7 rootstock which included 'Golden Delicious', (5 trees with 20 quadrants) and 'McIntosh' (4 trees with 16 quadrants). Acidic solutions at pH 2.75 and 3.25 were applied weekly, beginning June 11. Ambient rain served as a control on the unsprayed quadrants. Effects on leaf injury and fruit quality were observed.

Results and Discussion

Visible symptoms of acid rain on apple flowers were the same for all 3 cultivars tested in both years (Fig. 1). Necrotic lesions on flower petals developed rapidly and often were visible under acid droplets before they dried. Although solutions at pH 2.5 induced a massive amount of necrosis on petals, some lesions were also evident at pH 3.5. No lesions were evident at higher pH levels, nor were lesions visible on apple foliage at any pH. This contrasts with previous work from this laboratory in which *Malus hupehensis* seedlings grown under greenhouse conditions developed foliar lesions up to pH 3.5 (unpublished data). Grape leaves in the field developed lesions at pH 2.5 (12).

Ambient rainfall volume and acidity, to be used as a basis for comparing ambient controls with the simulated acid rain treatments, are reported in Table 1 for 1980 and 1981.

Some portions of exposed anthers and stigmas on individual flowers became necrotic at pH 2.5. Pollen collected from open flowers of 'Empire' trees after field treatment showed a significant reduction in germination when exposed to pH 2.5 (Table 2). This effect was previously reported for gaseous air pollutants (11, 16, 27).

In 1980, percentage of fruit set was influenced by total number of flowers for 'McIntosh' and 'Empire', but not for 'Golden Delicious', as determined by regression analysis. Adjusting for total number of flowers by analysis of covariance, we found a significant effect of acid rain (pH 2.5) on fruit set of 'McIntosh', in comparison to higher pH treatments, but not of 'Empire' (Table 2). There was no visible effect of acid rain on 'Golden Delicious' fruit set; however, there were few flowers on 'Golden Delicious' in 1980, which was a result of overcropping in the previous year that may have influenced response to treatment.

Table 4. Fruit russet, fruit firmness, seed number, and fruit weight of 'Golden Delicious' apple fruits grown without rain-exclusion chambers after weekly (1981 bloom to harvest) sprays with acid rain solutions and receiving ambient rain all season.

Acid rain solution (pH)	Fruit finish rating[z]	Fruit puncture pressure (kg)	No. seed/ fruit	Fruit wt (g)
3.0	2.6 a[y]	4.85 a	7.0 a	129 a
3.5	2.3 a	4.10 a	6.9 a	128 a
Control (ambient rainfall)	2.1 a	4.18 a	7.1 a	145 a

[z]Russet increasing in severity on a scale from 0–9
[y]Mean separation within columns by Waller-Duncan's BSD test, k = 100.

Table 3. Fruit set, fruit russet, fruit firmness, seed number, and fruit weight of 'Golden Delicious' apple fruits grown all season with or without ambient rain-exclusion chambers after 1981 bloom-time spray with acid rain solutions.

Acid rain solution (pH)	Fruit set (%)	Fruit finish rating[z]	Fruit puncture pressure (kg)	No. seed/ fruit	Fruit wt (g)
Without exclusion chamber					
2.5	26.4 a	2.6 a[y]	4.22 ab	7.0 b	123 bcd
3.0	25.6 a	2.4 a	4.29 ab	7.1 b	113 d
3.5	25.1 a	2.5 a	4.14 bc	7.0 b	120 cd
4.0	28.5 a	2.8 a	4.07 bc	7.3 ab	121 cd
4.5	27.5 a	2.6 a	4.07 bc	7.3 ab	118 d
5.5	25.1 a	2.8 a	4.44 a	7.0 b	117 d
Control (ambient rainfall)	26.9 a	2.4 a	4.33 ab	7.4 ab	114 d
With Exclusion Chamber					
3.0	26.0 a	0.6 b	3.73 d	7.2 ab	136 ab
4.0	28.2 a	1.0 b	3.62 d	7.6 a	139 a
Control (no rain)	28.6 a	0.7 b	3.62 d	7.7 a	133 abc

[z]Russet increasing in severity on a scale from 0–9
[y]Means separated within columns by Waller-Duncan's BSD test, k = 100.

Table 5. Red color, fruit firmness, fruit weight, and soluble solids of 'McIntosh' apple fruits grown without rain-exclusion chambers after weekly (1981 bloom to harvest) sprays with acid rain solutions and receiving ambient rain all season.

Acid rain solution (pH0	Color (% red)	Fruit puncture pressure (kg)	Fruit soluble solids (%)	Fruit wt (g)
2.75	81.2 a	5.71 a[z]	13.4 a	124 b
3.25	80.9 a	5.52 b	13.4 a	135 a
Control (ambient rainfall)	77.5 a	5.52 b	13.2 a	130 a

[z]Means separated within columns by Waller-Duncan's BSD test, k = 100.

There were no obvious differences in apple size, color, or shape at harvest that could be attributed to acid rain treatment at bloom.

Field experiments conducted in 1981 showed no significant reduction in pollen germination in the cultivar 'Empire' at pH 2.75, in contrast to reduction in 1980 at pH 2.5.

The effects of acidic precipitation were compared on 'Golden Delicious', with or without rain-exclusion chambers, as separate and pooled experiments (Table 3). Separately, we observed few significant differences in the measured parameters. Differences in fruit set which were observed for 'McIntosh' in 1980 again were not seen for 'Golden Delicious' in 1981. Fruit russetting was not affected by rain acidity. Fruit puncture pressure, a measure of the firmness of the fruit which predicts ripeness, was significantly higher at pH 5.5 in comparison to pH 3.5, 4.0, and 4.5. Seed numbers per fruit and weight per fruit were unaffected by rain acidity. However, when these treatments were pooled, significant effects of the rain-exclusion chambers (Table 3), produced less fruit russetting in the chamber as previously reported (7). The presence of rain-exclusion chambers significantly increased the rate of fruit ripening as measured by fruit puncture pressure and tended to increase seed numbers per fruit although these differences were not significant. This corresponded to increases in fruit weight as observed in earlier studies (1).

Weekly sprays on 'Golden Delicious' trees did not significantly affect fruit finish, ripeness, seed number, or fruit weight (Table 4). However, higher fruit pressure (delayed ripening) resulted from season-long sprays of acid rain at pH 2.75 on 'McIntosh' trees in comparison to pH 3.25 and ambient rainfall (Table 5). Fruit color and percentage of soluble solids were unaffected, but fruit weight was reduced at the low pH treatment. It is concluded that rain in the range of pH 3.2 to pH 5.8 (ambient range for Geneva, N.Y. in 1980 and 1981) produced no negative effect on the productivity of apple trees when treated with simulated acid rain at the flowering stage or later. Some fruit quality effects were visible at pH 2.5 and pH 2.75 (subambient levels). Later ripening of an already late-ripening cultivar like 'Golden Delicious' may have a significant negative economic impact. Any reductions in pollen germination and fruit set at low pH levels, although significant for some cultivars, may or may not be economically significant since in many cases pollen germination and fruit set are not the limiting factors to yield. Actual threshold levels of damage must be determined with further research. Cultivars other than 'Golden Delicious', which is a 'biennial bearer', should be examined for fruit set reduction.

Literature Cited

1. Anonymous. 1930. Agricultural experiments 1929. Bul. New Hampshire Agr. Expt. Sta. 250.
2. Blanpied, G. D. 1979. Effect of artificial rain water pH and calcium concentration on the calcium and potassium in apple leaves. HortScience 14:706–708.
3. Blanpied, G. D. and G. H. Oberly. 1978. Calcium and magnesium levels in the annual rings of 'McIntosh' apple wood. J. Amer. Soc. Hort. Sci. 103:638–640.
4. Buttrose, M. S. 1974. Climatic factors and fruitfulness in grapevines. Hort. Abstr. 44:319–326.
5. Byers, M. A. 1977. A scarfskin-like disorder of apple. HortScience 12:226–227.
6. Creasy, L. L. 1980. The correlation of weather parameters with russet of 'Golden Delicious' apples under orchard conditions. J. Amer. Soc. Hort. Sci. 105:735–738.
7. Creasy, L. L. and H. J. Swartz. 1981. Agents influencing russet on 'Golden Delicious' apple fruits. J. Amer. Soc. Hort. Sci. 106:203–206.
8. Evans, L. S., N. F. Gmur, and F. Da Costa. 1978. Foliar response of six clones of hybrid poplar to simulated acid rain. Phytopathology 68:847–856.
9. Evans, L. S. and T. M. Curry. 1979. Differential responses of plant foliage to simulated acid rain. Amer. J. Bot. 66:953–962.
10. Faust, M. and C. B. Shear. 1972. Russeting of apples, an interpretive review. HortScience 7:233–235.
11. Feder, W. A. 1981. Bioassaying for ozone with pollen systems. Environ. Heath Perspectives 37:117–123.
12. Forsline, P. L., R. C. Musselman, W. J. Kender, and R. J. Dee. 1983. Effects of acid rain on grapevines. Amer. J. Enol. Vitic. 34:17–22.
13. Haines, B., M. Stefani, and F. Hendrix. 1980. Acid rain: threshold of leaf damage in eight plant species from a southern Appalachian forest succession. Water, Air Soil Pollut. 114:403–407.
14. Jacobson, J. S. and P. van Leuken. 1977. Effects of acidic precipitation on vegetation. Proc. 4th Intern. Clean Air Congress. Tokyo, Japan.
15. Jacobson, J. S. 1980. The influence of rainfall composition on the yield and quality of agricultural crops. Proc. Intern. Conf. Ecol. Impact Acid Precip. Norway.
16. Karnoski, D. F. and G. R. Stairs. 1974. The effects of SO_2 on *in vitro* forest tree pollen germination and tube elongation. J. Environ. Qual. 3:406–409.
17. Kender, W. J. and F. H., F. G. Spierings. 1975. Effects of sulfur dioxide, ozone, and their interactions on 'Golden Delicious' apple trees. Neth. J. Plant Path. 81:149–151.
18. Lee, J. J., G E. Neely, and S. C. Perrigan. 1980. Sulfuric acid rain effects on crop yield and foliar injury. EPA-600/3-80-016. U.S. EPA Environmental Research Laboratory, Corvallis, Ore.
19. Lee, J. J., G. E. Neely, S. C. Perrigan, and L. C. Grothaus. 1981. Effects of simulated sulfuric acid rain on yield, growth and foliar injury of several crops. Environ. & Expt. Bot. 21:171–185.
20. Miller, P. M. and S. Rich. 1968. Ozone damage on apples. Plant Dis. Rptr. 52:730–731.
21. Murdy, W. H. and H. L. Ragsdale. 1980. The influence of relative humidity on direct sulfur dioxide damage to plant sexual reproduction. J. Environ. Qual. 9:493–496.
22. Paparozzi, E. T. and H. B. Tukey, Jr. 1980. Leaf surface injury

by simulated acid precipitation on *Betula alleghaniensis*. HortScience 15:402. (Abstr.).
23. Przybylski, Z. 1979. Badania Nad Wplywem Na Agrocenozy Atmosferv Skasonej Zwiazkami Siarki (Eng. summary). Rrace Naukowe Instytutu Ochrony Roslin. Tom XXI Zeszyt 1:63–103.
24. Shaulis, N. J. and C. Pratt. 1965. Grapes, their growth and development. Farm Research Reprint 401. N.Y. State Agr. Expt. Sta.
25. Shertz, R. D., W. J. Kender, and R. C. Musselman. 1980. Foliar response and growth of apple trees following exposure to ozone and sulfur dioxide. J. Amer. Soc. Hort. Sci. 105:594–598.
26. Stasiuk, W. N., P. E. Coffey, and R. F. McDermott. 1975. Relationships between suspended sulfates and ozone at a non-urban site. Paper 75-627, 68th Air Pollution Control Assn. Conf.
27. Varshney, S. R. K. and C. K. Varhsney. 1981. Effect of sulphur dioxide on pollen germination and pollen tube growth. Environ. Pollution Ser. A. 24:87–92.
28. Way, R. D. 1978. Pollination and fruit set of fruit crops. New York's Food and Life Sciences Bul. 76.
29. White, G. B. 1981. The outlook for fruit in the Northeast. Cornell Agr. Econ. Staff Paper 81-23.

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